Effects of Surface Mining and Residential Land Use on Headwater Stream Biotic Integrity in the Eastern Kentucky Coalfield Region

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Effects of Surface Mining and Residential Land Use on Headwater Stream Biotic Integrity in the Eastern Kentucky Coalfield Region

by

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This report has been approved for release:

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Executive Summary

The Kentucky Division of Water's (KDOW) surface water monitoring programs rely on biological, chemical, and habitat information to make science-based judgments on aquatic life use-support designations. This report documents biological impairment to macroinvertebrate communities in headwater streams primarily disturbed by surface coal mining and residential land use in eastern Kentucky. These two primary land uses are considered to be long-term and geographically pervasive throughout eastern Kentucky.

In order to assess waterbody health, KDOW compares stream data to reference conditions. The reference condition collectively refers to the range of quantifiable ecological elements (i.e., chemistry, habitat and biology) that are found in least-disturbed environments. KDOW has an extensive reference reach network (>200 sites) located throughout the Commonwealth. Nearly half of these streams are located in headwater watersheds. In the Eastern Coalfield Region (ECF), KDOW utilizes approximately 40 headwater reference sites to set criteria for aquatic life use designations. Headwater streams are important resources that serve multiple functions (e.g., water supply, waste assimilation, flood control and ecological values) often overlooked in environmental planning and land-use decision making. These sometimes intermittent waterbodies (primarily 1st and 2nd order streams) serve as the key interface between the surrounding landscape and larger waterbodies and provide high quality water for downstream uses (Yoder et al. 2000, Wallace and Meyer 2001).

Although state and federal regulatory requirements to protect water quality exist, impacts to streams due to surface mining are still common and widespread. Surface mining impacts streams both chemically and physically by increasing dissolved solids (e.g., sulfate, calcium carbonate) and sediment loading, and by removing riparian forest vegetation. Residential development in the ECF headwaters probably has the least oversight with regard to the protection of aquatic resources. Both home site construction and occupation within and adjacent to stream corridors can seriously impact aquatic species and their habitats through stream channelization and by increasing nutrients and organic wastes, sediment loads and removing riparian forest vegetation. Other impacts to ECF headwater streams arise from timber harvesting, road construction, oil and gas development, and light agriculture.

A total of 83 sites (38 reference sites and 45 disturbed sites) with watershed areas less than four square miles were sampled for macroinvertebrates and habitat and physicochemical parameters. These data were collected over a four-year period between 2000 and 2004, with the majority of the data collected between 2000 and 2002. Headwater streams were sampled between mid-February and late-May (spring index period). Sites were categorized *a priori* into one of four groups (reference, residential, mined/residential, and mined) based on the predominant land use upstream of the sampling reach. Macroinvertebrate sampling was conducted in accordance with *Methods for Assessing Biological Integrity of Surface Waters in Kentucky* (KDOW 2002). Physicochemical parameters (conductivity, pH, dissolved oxygen, and stream temperature) were collected and habitat features were scored with the EPA Rapid Bioassessment Protocol (RBP) Habitat Assessment procedure following Barbour et al. (1999). Stream canopy closure was also estimated in each reach and scored.

Sites were assessed with the Kentucky Macroinvertebrate Bioassessment Index (MBI), an aggregate index that incorporates seven metrics: 1) total generic taxa richness 2) total generic EPT richness; 3) the modified Hilsenhoff Biotic Index (mHBI); 4) the modified %EPT, which excludes the tolerant caddisfly *Cheumatopsyche*; 5) %Ephemeroptera abundance; 6) %Chironomidae+%Oligochaeta abundance; and 7) %Clingers. Exploratory box plots and scatter plots were viewed along with Pearson correlation coefficients and linear regression to evaluate

relationships between environmental and biological data. Multivariate techniques included principal components analysis (PCA), stepwise discriminant function analysis (DFA), and correspondence analysis (CA). Significance tests were performed on environmental and biological parameters between the reference and the other three land-use categories with the non-parametric Kruskal-Wallis multiple comparison z-value (rank sum) test.

There were significant differences in conductivity ($p<0.05$) between most categories, but reference and residential sites were not significantly different. Reference sites averaged 63 μS/cm, while residential, mined/residential, and mined sites averaged 195, 552, and 1096 μS/cm, respectively. pH was significantly higher ($p<0.05$) at mined sites than at reference and residential sites. Reference and residential sites were not significantly different, nor was residential versus mined/residential sites. Reference sites averaged 6.7 while residential, mined/residential, and mined sites averaged 7.3, 7.8, and 8.0 S.U., respectively. Reference streams were significantly higher in total habitat scores ($p<0.05$) but no substantial differences were detected between residential, mined/residential, and mined sites. The average reference habitat score was 169 (out of 200), while residential, mined/residential, and mined sites averaged 136, 130, and 130, respectively. Canopy scores were significantly highest at reference sites ($p<0.05$). Mined/residential sites had significantly lower canopy scores than mined or residential sites.

The dispersion of disturbed sites in PCA ordination space clearly demonstrated that habitat and physicochemical factors deviated from the reference condition. The RPB total habitat score had the highest factor loadings on axis 1 followed by RBP epifaunal substrate score and conductivity. Taxonomically, visual inspection of the CA ordination suggested that reference communities were highly similar to each other. However, substantial departure of most residential and mined sites from the reference site array indicated very different community makeup. This analysis also demonstrated distinct separation of assemblages from mined sites versus residential sites. Mined/Residential streams were different from the reference site cluster and plotted fairly evenly throughout mined and residential clusters in ordination space.

Streams from the three disturbed categories had significantly lower MBI scores, taxa richness, EPT richness, m%EPT, %Ephem and %Clingers, and significantly higher mHBI and %Chir+Olig values than reference sites ($p<0.05$). The MBI and its associated metrics were significantly correlated ($p<0.05$) to conductivity, pH, RBP total habitat score, the RBP embeddedness score, epifaunal substrate score, and sediment deposition score, with correlation coefficients greater than $\pm$ 0.45. Between the three disturbed landuse categories, a slight pattern was detected graphically that distinguished effects of individual land uses from conductivity influences, but not habitat quality. The wholesale loss of mayflies (%Ephemeroptera and Ephemeroptera richness) at mined sites indicated that these organisms are especially sensitive to coal mine drainage. Dissolved solids emanating from hollowfills are a primary cause of biological impairment because of their severe impact to mayflies (a key component of headwater stream communities) and other sensitive taxa. Some residential sites produced similar harmful conditions for mayflies that may be linked to excessive nutrient and organic loading.

Overall, the MBI indicated nearly all (90-95%) of the streams with mined, residential, and mined/residential land use were impaired. The data presented here indicated that macroinvertebrate communities are extremely sensitive and vulnerable to the land uses that are most pervasive throughout eastern Kentucky (i.e., mining and residential). Both mining and residential impacts are unquestionably long term (decades or centuries), and are not likely to be eliminated by current regulatory efforts.

1.0 Introduction

The Kentucky Division of Water (KDOW) in the Department for Environmental Protection (DEP) is responsible for monitoring and assessing the ecological health of waterbodies across the Commonwealth. The primary focus of the Water Quality Branch of KDOW is upon surface waters ranging from small headwater streams to large rivers. Various land uses in the Commonwealth impart multiple impacts from both point and nonpoint sources to aquatic resources. This report documents biological impairment in headwater streams primarily disturbed by surface coal mining and residential land use in eastern Kentucky. These two primary land uses are long-term and geographically pervasive throughout eastern Kentucky. The heavily dissected Appalachian Plateau in eastern Kentucky (referred to hereafter as the Eastern Coalfields, or ECF) is drained by thousands of small headwater streams that ultimately feed hundreds of mid-sized streams and five major rivers (Big Sandy, Little Sandy, Licking, Kentucky and Upper Cumberland).

KDOW's surface water monitoring programs rely on biological, chemical, and habitat information to make science-based judgments on aquatic life use-support designations. Biological communities integrate and reflect environmental conditions; therefore, benthic invertebrate data were collected to further investigate degrees of impacts indicated by differences in water-quality at headwater sites scattered throughout the ECF. Although the KDOW routinely integrates three biological assemblages (algae, macroinvertebrates, and fish) in their water quality assessments, this investigation focuses only on macroinvertebrates. Benthic invertebrate populations are critical elements of aquatic food webs, and they possess many characteristics that make them good indicators of instream conditions (Cairns and Pratt 1993, Resh and Jackson 1993). Moreover, the use of invertebrate indicators in headwater streams is preferred since many of these streams have naturally depauperate fish communities because of their small size and steep gradients.

1.1 Importance of Headwater Streams

Headwater streams serve multiple functions (e.g., water supply, waste assimilation, flood control and ecological values) often overlooked in environmental planning and land use decision making. These often intermittent waterbodies (primarily 1st and 2nd order streams) serve as the key interface between the surrounding landscape and larger waterbodies and provide high quality water for downstream uses (Yoder et al. 2000, Wallace and Meyer 2001). Small 1st-2nd order streams represent the majority of shoreline within any drainage network and make up 86% of total stream length in the U.S. (Leopold et al. 1964). Because these small streams are so closely connected to their watersheds (Hynes 1975), terrestrial disturbances can result in severe and enduring impacts, which ultimately can affect both local and downstream environments (Webster et al. 1992). Brinson (1993) argued that the highest priority should be placed on protection of headwater streams and wetlands because of their close proximity to the surrounding landscape causes pronounced impacts cumulatively affecting downstream water quality.

In general, natural headwater streams in the ECF are narrow, shallow, cool, heavily shaded, and low in nutrients and dissolved ions. They are predominately heterotrophic, where energy is derived from allochthonous organic material provided by riparian vegetation (e.g., leaves, sticks and large woody debris). In contrast to larger wadeable streams and rivers, headwater streams are most susceptible to pollutant loading, having lower capacity for pollutant dilution and assimilation. The basic chemical composition of unpolluted streams draining a landscape is largely established and controlled in headwater streams (Gibbs 1970, Likens 1999, Johnson et al. 2000). Biotic uptake by vegetation, transformation by microbes in soils, riparian zones, and streams, in the presence of available carbon is an important mechanism controlling export of nitrogen from watersheds (Hedin et al. 1998). Small streams in the network are the sites of the most active uptake and retention of dissolved nutrients (Alexander et al. 2000, Peterson et al. 2001). Moreover, KDOW has found that higher proportions of sensitive and vulnerable species occupy headwater streams (Pond et al. 2003, KDOW unpub. data). Morse et al. (1997) stated that the Appalachian Mountains harbor many sensitive macroinvertebrates such as insects of the orders Ephemeroptera, Plecoptera and Trichoptera (EPT). The many endemic and rare species have been attributed to the diverse geological, climatological, and hydrological features of the region.

1.2 Reference Conditions

In order to characterize stream community health, biological, chemical, and physical data are compared to conditions found at reference streams (Hughes 1995). Reference streams are those that are least-impacted for a given geographic region, and theoretically should support rich and diverse communities with many pollution sensitive species and fewer tolerant species. Pond et al. (2000, 2003), and Pond and McMurray (2002) reported that the ECF region was relatively homogeneous with respect to the types of macroinvertebrate communities found at reference sites. Therefore, KDOW classifies the region collectively as the Mountain Bioregion. This region encompasses portions of three Level III ecoregions (Southwestern Appalachians [69], Central Appalachians [69] and the Western Allegheny Plateau [70] after Woods et al. [2002]). By comparison, the Mountain Bioregion (synonymous with the ECF region) macroinvertebrate fauna is distinct from other Kentucky bioregions (e.g., Bluegrass, Pennyroyal, Mississippi Valley-Interior Lowlands). Figure 1 shows an example of a headwater reference site in the ECF.

Figure 1. A headwater reference stream in Breathitt County.

Acknowledging past and present environmental stresses is important when considering reference sites. Natural disturbances from floods, droughts, windstorms, landslides, fires, and other phenomena were present in eastern Kentucky long before humans began to change the landscape. These disturbances, while either catastrophic or benign, have helped to shape the natural, expected aquatic community (Poff and Ward 1989). The hydrological conditions of forested watersheds in Kentucky were severely altered by logging in the early 1900s. Undoubtedly, severe erosion carried vast amounts of sediment into the stream channels. Many streams were used for log transport where channels were altered by the removal of obstructions such as large boulders and logs, and splash dams were built to provide high flows for transporting logs downstream. Evidence of this practice still remains in many streams in University of Kentucky’s Robinson Forest where KDOW has several reference sites. Moreover, the once-forested steep slopes were often tilled for row crop agriculture after initial clear-cutting in the early 1900s, and small streams were frequently moved to one side of their valleys to accommodate farming or home building in the bottomlands. While there are no scientific data on the effects of these widespread activities, one can only speculate about the profound impacts to small headwater streams. In light of these historical impacts, reference streams selected by KDOW still represent the least-disturbed condition.

The reference condition collectively refers to the range of quantifiable ecological elements (i.e., chemistry, habitat and biology) that are found in least-disturbed stream environments. In Kentucky, finding reference streams can be a difficult task, because no regions are entirely without areas of some human disturbance. Ultimately, the application of the reference condition involves its comparison to streams exposed to various levels of environmental stress using defined sampling methodology and assessment criteria (KDOW 2002a). Impairment would be detected if indicator measurements (e.g., biological indices, habitat rating, chemical concentrations) fall outside the range of threshold criteria established by the reference condition (i.e., deviation below the reference distribution).

1.3 Primary Land-use Disturbances in the ECF

Stressors arising from mining, silviculture, residential and commercial development, agriculture, and road, railroad and bridge construction primarily affect watersheds in the ECF region. In the northern- and western-most parts of the ECF region (subecoregions 70h and 70b [after Woods et al. 2002]), agricultural impacts (e.g., livestock, row cropping, conversion of forest to pastureland) are more common than in the southern and eastern-most portions (subecoregions 69d-e and 68c [after Woods et al. 2002]). In the heart of the ECF region, mining operations and residential development are most pronounced in smaller watersheds where headwater mountain streams are exposed to more direct and profound physical and chemical disturbances.

1.3.1 Surface Mining Impacts

Although state and federal regulatory requirements for point and nonpoint sources to protect water quality exist, impacts to streams due to surface mining are still common and widespread (KDOW 2004, KDOW 2002b, KDOW unpub. data). Episodic releases of solids stemming from blackwater spills (i.e., coal slurry) and general mine operation runoff or releases can cause harm to aquatic biota. Chronic detrimental releases such as high concentrations of dissolved ions (e.g., sulfate) from hollowfills and other acid and non-acid mine drainage can have longer lasting effects, curtailing re-colonization and recruitment of sensitive invertebrate populations.

Physical impacts of mining and associated road construction and use include sedimentation and removal of riparian vegetation and associated organic matter inputs. Minor to severe sedimentation can occur as “pulse” events (blackwater releases, construction or failure of instream sediment ponds, culverts, or bridges) or as “press” events (mine site runoff, continual road runoff, poor BMP implementation). Furthermore, soil compaction and the presence of impoundments, roads, bridges, and culverts can contribute to excess sediment loading through modification of the hydrological regime (e.g., flow impediments, channel scour, stream bank failure). Figures 2, 3, 5, and 6 show typical mined landscapes in various stages of activity.

Many studies have documented that streams receiving drainage from mined areas exhibit several characteristics not found in unmined watersheds: 1) altered water-quality conditions (Curtis 1973, Dyer 1982, Hren et al. 1984, U.S. EPA 2002a); 2) increased sediment loads (Parker and Carey 1980, Osterkamp et al. 1984); 3) increased hydrologic response time to storm events (Bryan and Hewlett 1981), 4) altered flow duration curves (USGS 2001b), and 5) altered or changed channel morphology (A. Parola, Univ. of Louisville, pers. comm). These changes in the physical and chemical properties of stream environments can affect benthic invertebrate community structure and composition (Bradfield 1986, Green et al. 2000, Fulk et al. 2003).

Figure 2. View of a large contour surface mine in Bell County.

Figure 3. Lower end of an active mine in Upper Pigeon Branch, Pike County. More than 75% of this 2 sq. mile watershed (2nd order) was disturbed by mining activities. The site was located approximately 500 m downstream of this view. Conductivity and nitrate concentrations were highly elevated.

Mining significantly alters the chemistry of aquatic environments (Curtis 1973, Branson and Batch 1972, Minear and Tschantz 1976, Dyer 1982, U.S. EPA 2002b, Hartman et al. 2004). Acid mine drainage (AMD) is not as common in the ECF as it once was as enforcement, newer technology and mining methods have mostly eliminated it. However, sulfates are produced during surface mining, often in the form of calcium, magnesium, and iron complexes. Following mining, calcium, magnesium, manganese, and sulfate concentrations increase in a systematic fashion with the passage of time (Curtis 1973). Sulfate and conductivity is probably the most useful chemical indicator of the condition of a stream in mined watersheds in the ECF (Rikard and Kunkle 1990), and its concentration reflects the extent of watershed disturbance. Following a period of sulfate generation at the onset of mining, long-term production of the substance continues from mined watersheds (Minear and Tschantz 1976). Generally, high specific conductivity and concentrations of dissolved solids and hardness result from leaching of salts from crushed overburden (U.S EPA 2002a). In valley fills, Wunsch et al (1996) found that water emanating from the fills was calcium–magnesium–sulfate type water resulting from pyrite oxidation and calcite dissolution along the groundwater flow path.

General coal mine drainage (CMD) often causes physical and chemical impacts to streams as a result of the precipitation of entrained metals and sulfate, which become unstable in solution (U.S. EPA 2002a). Iron and aluminum usually precipitate as hydroxides, forming orange or white sludge (i.e., "yellow boy") that coats stream substrates. In addition, most mined streams in the ECF have elevated calcium in solution (Dyer 1982), and if pH is sufficiently elevated, gypsum ($CaSO_4$) will also precipitate (U.S. EPA 2002a). These sludge-like materials smother the stream bottom, armoring the substrate, thus inhibiting the feeding and reproduction of stream organisms. In addition, other precipitants such as calcium carbonate ($CaCO_3$) increase dramatically in receiving streams during and after mining operations. This calcium carbonate precipitates as a hard, encrusting and cementing substance. This substance also coats stream substrates and makes them unsuitable for colonization by invertebrates. Figure 4 shows a leaf pack broken off of a woody debris dam that had solidified with $CaCO_3$ and ferrous oxide.

Figure 4. A leaf pack cemented by $CaCO_3$ and ferrous oxide. This piece was broken off a larger debris dam in a headwater stream in Martin Co. affected by surface mining. The conductivity was 2350 μS/cm and the pH was 9.13 S.U.

Little is known about how or if heavy metals from CMD are responsible for aquatic life impacts in the EFC. Much argument has been made stating that elevated water hardness from current mining technology helps to control the bioavailablity of most metals. What is not known is whether biological processes, either in biofilms or through ingestion and digestion of particles, can make these metals bioavailable by the organisms themselves. Although water column samples contain only small quantities of dissolved or total metals, the bottom sediments may contain considerable quantities (Chapman 1978), usually attributed to adsorption on streambed materials or co-precipitation with the oxides and hydroxides of aluminum, iron, and manganese. Metal toxicity is dependent on the availability of the dissolved metal to the affected organisms, the exposure duration, and a host of other parameters. In situations where both iron and manganese are elevated, blooms of filamentous bacteria (*Leptothrix*) may smother benthic habitats. Sheaths of this iron-depositing bacterium have been known to be deleterious to macroinvertebrates by causing substrate avoidance, food quality limitations, and toxicity (Wellnitz et al. 1994).

Although KDOW has few data on nutrient concentration below mined-only watersheds, there is some evidence that shows surface mining leads to elevated nutrient levels. Moreover, increased nuisance algal growth has been observed below mining operations (pers. obs). Data from KDOW and University of Louisville researchers (J. Jack unpub. data) revealed roughly an 800 percent increase in nitrate levels above background conditions, although total phosphorus concentrations rose only by 50-75 percent. The elevated nitrate levels likely stem from careless handling or erosion of nitrate compounds used for explosives (U.S. EPA 2002a), runoff from nitrogenous fertilizers used in reclamation activities, and increased nitrogen export from loss of surrounding forest vegetation (Golladay 1988, Arthur et al. 1998).

Figure 5. Eastern Kentucky hollowfill setting showing typical worksite for pond cleanout and removal activities.

Figure 6. Close-up view of pond cleanout activities. Note the flow coming out of the toe of the hollowfill. The conductivity in receiving stream was 1235 μS/cm .

1.3.2 Residential Impacts

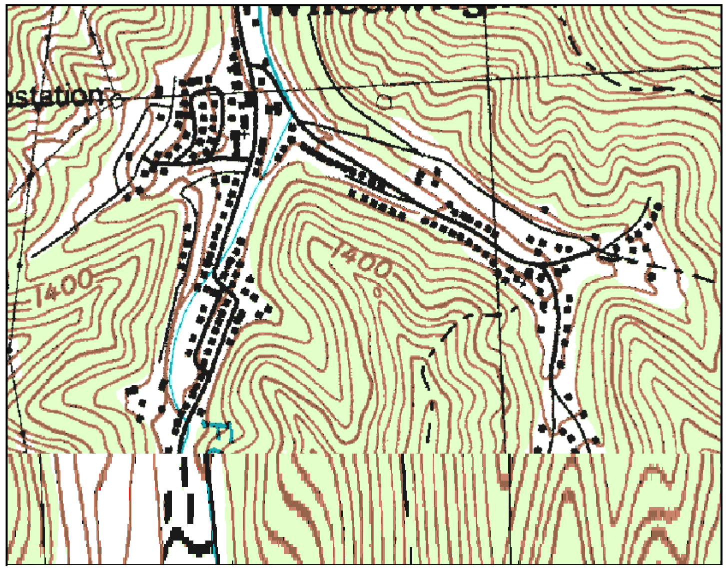

Figure 7. Close up view of 7.5 min topographic map in Floyd Co. showing high residential density along headwater streams.

Residential development in the ECF headwaters probably has the least oversight with regard to the protection of aquatic resources. Both home site construction and occupation within and adjacent to stream corridors can severely impact aquatic species and their habitats. In the ECF region, many people live along small headwater streams (Figure 7) generally because of topographic limitations. Many of these streams have undergone localized channel changes to accommodate roads and housing, thus directly modifying instream habitat and indirectly affecting the natural flow regime. Moreover, increases in the impervious surface area causes streams to be more flashy and susceptible to channel scouring. Nutrient loading from residential activities can increase filamentous algal productivity that can ultimately smother important benthic habitats and alter invertebrate community integrity. Moreover, increases in nutrient concentrations in these normally nutrient poor headwater streams may stimulate blooms of filamentous bacteria (e.g., *Sphaerotilus*) that negatively affect macroinvertebrates (Lemly 1998, 2000). Even more harmful, elevated ammonia concentrations from untreated organic wastes can reach acute levels toxic to many aquatic taxa.

Figure 8. View of sampling location downstream of map view shown in Figure 7 above.

The primary impact to aquatic organisms below unsewered high residential use areas stems from high organic loading from straight-pipe sewage and failing septic systems. Toxic, domestic household chemicals are also directly flushed into nearby streams. There are an estimated 15,000 straightpipes and an additional 15,000 failing septic systems in eastern Kentucky (KWRRI, 2002). Although efforts by eastern Kentucky PRIDE (a non-profit group) are being made to improve on-site wastewater treatment and provide sewer services in the ECF region, the magnitude of this problem will continue to have long-term impacts on water resources. Figures 9 and 10 highlight some typical problems associated with residential areas in the ECF.

Figure 9. View of a channelized headwater stream in a residential setting.

Figure 10. Solid waste accumulations in a wadeable stream in Floyd Co.

1.4 Other Types of Land-use Impacts

1.4.1 Logging Impacts

Timber harvesting can have profound effects on ecosystem-level processes, biological communities, and flow patterns (Webster et al. 1992, Likens et al. 1970). Most studies only address the impacts of clear-cutting; a method seldom practiced in Kentucky (Kentucky Division of Forestry, pers. comm.) except in site preparation for mining or highway projects (e.g., “clearing and grubbing”).

Soil disturbance associated with timber harvest can result in high sediment yields. Overland flow and erosion of mineral sediments into stream channels are promoted when these disturbances remove the litter layer or compact forest soils. This is often only a temporary impact since sediment yield decreases as natural vegetation reestablishes. However, severe erosion occurs when operators use stream channels illegally as skid trails (Figure 11). According to Leopold et al. (1964), stream channel morphology and associated habitats are directly influenced and maintained by eight major variables: channel width, depth, flow velocity, discharge, channel slope, roughness, sediment load, and sediment size. A change in any one of these variables will set in motion consequent changes in the other variables altering the structural attributes of the stream channel. The complex physical habitat that sustains resident biota depends upon the dynamic equilibrium sustained by the interaction of these variables. Thus, impacts associated with logging (or other watershed disturbance) that would change one or more of these variables such as the widening of channels for use as skid trails, changes in sediment load and sediment size due to changes in erosion patterns, increases in flow velocities due to the removal of canopy cover and floodplain roughness would cause channel instability and impair the stream's capacity to sustain complex physical habitat. The effects of such channel changes may be either long-term or short-term. In addition, by altering the flows of water and sediment, stream reaches above and below the impacted areas may be destabilized (Niemann et al. 2001, Tucker et al. 2001).

Figure 11. A headwater stream illegally used as a skid trail for logging operations.

Dissolved mineral loading may be increased slightly by harvesting but also declines quickly as vegetation reestablishes (Swank and Douglas 1977). Golladay (1988) and Arthur et al. (1998) found increases in nitrogen and phosphorus export in logged catchments in the Appalachians but minor differences in calcium, potassium, or sulfate concentrations between logged and undisturbed watersheds. Likens et al. (1970) actually found sulfate concentrations to decrease following clear cutting and experimental suppression of forest growth by herbicides.

Removing overhanging vegetation along heavily shaded headwater streams increases insolation, resulting in increased average temperatures. This is important since many headwater species have very narrow thermal tolerances. However, the duration of the temperature increase is typically short-lived (~5 years), with temperatures returning to pre-disturbance levels once the canopy closes over the stream (Swift 1983). Furthermore, removal of streamside vegetation results in a loss of allochthonous food material and may lead to stream bank stability problems.

1.4.2 Oil and Gas Impacts

The exploration and extraction of oil and gas reserves has also left a footprint on the landscape in the ECF region. There are more than 30,000 active and inactive wells in the ECF alone (Kentucky Geological Survey GIS layer). Prior to Kentucky's enactment and enforcement of stricter water regulations in the 1980's, brine wastes caused severe salinization of streams impairing many waterbodies. During the drilling and pumping process, brine water can migrate up through improperly cased wells and seep into nearby streams and groundwater. Elevated conductivity from chlorides (frequently > 10,000 μS/cm) can have dramatic effects on stream fishes, invertebrates, and algal communities (KDOW 1986, 1989, 1990). Fortunately, most of these streams have undergone complete recovery (KDOW unpub. data) following cessation of oil extraction or proper containment and disposal of brine water. Land disturbance associated with oil/gas production is generally minimal, but poor BMP implementation on access roads and at the worksite can increase sedimentation in nearby streams (pers. obs.). In some headwater areas, access roads are illegally located directly within the stream channel, causing severe sedimentation and habitat degradation.

1.4.3 Road Impacts

Roads that cross or lie near stream channels affect both the route and time in which storm water takes to reach the aquatic system. The results are intensified erosion, increased sediment loading, and changed runoff patterns. Reid and Dunne (1984) found that heavily used gravel roads contributed more than 100 times as much fine sediment as an abandoned road or a paved road. With paved roads, most of the sediment came from the associated ditches and cut slopes. Often, improperly placed and sized culverts contribute to local erosion and sedimentation both upstream and downstream of the crossings (Wellman et al. 2000, Warren and Pardew 1998).

There are few roadless watersheds in Kentucky. Numerous KDOW reference sites have gravel, paved, or grassed roads along their corridors. Indeed, some of these roads locally contribute noticeable amounts of sediments or cause stream bank stability problems. KDOW believes that using some reference sites with roads is acceptable and allows for a more realistic concept of attainability. The logic here is that most roads are permanent, and that total removal of roads from small watersheds, especially on private land, is impractical. However, roads and associated culverts or bridges placed with little or no oversight could damage stream channels to the point that the stream would not be considered reference quality.

2.0 Methods

2.1 General Study Area

The study region includes parts of the Southwestern Appalachian (68), Central Appalachian (69), and Western Allegheny Plateau (70) Level III ecoregions (Woods et al. 2002) in Kentucky (Figure 12a). All ecoregions lie within the Eastern Coalfield Physiographic Province (or Appalachian Plateaus Province), which makes up approximately 31% of the Commonwealth. This area is characterized by dissected terrain with similar forest types, geology, and climate. Bedrock geology is sedimentary and consists of interbedded sandstones, siltstones, shale, and coal and the dominant vegetation is part of the mixed mesophytic forest classification (Braun 1950). Common tree species found along reference streams include eastern hemlock, beech, maples, oaks, hickories, buckeye, and tulip tree. Common shrubs include spicebush, witch hazel, pawpaw, rhododendron, hydrangea, and ironwood. Headwater streams in this region typically flow through constrained valleys with high gradients and have boulder-cobble substrates. Precipitation patterns are generally uniform throughout the study region. In 1999, the summer prior to the onset of intensive data collection in headwater streams by KDOW, the eastern Kentucky region attained both severe and extreme drought status (Drought Mitigation Center 2001). Annually, the regional drought of 1999 fell near the 5th percentile for normal annual precipitation with a recurrence interval of more than 20 years (Institute for Water Resources 2001).

2.2 Site Selection

All biological, habitat, and chemical data used in these analyses are stored in KDOW's Ecological Data Application System (EDAS, v. 3.01) database. A total of 83 sites (38 reference sites and 45 disturbed sites) with watershed areas less than four square miles were used in this study (Figure 12b; Appendix A). These data were collected over a four-year period between 2000 and 2004, with the majority of the data collected between 2000 and 2002. Headwater streams were sampled between mid-February and late-May (spring index period). This is the period when macroinvertebrates are most diverse and abundant in headwater streams and therefore provides the most information for assessment purposes (Pond 2000, KDOW unpub. data).

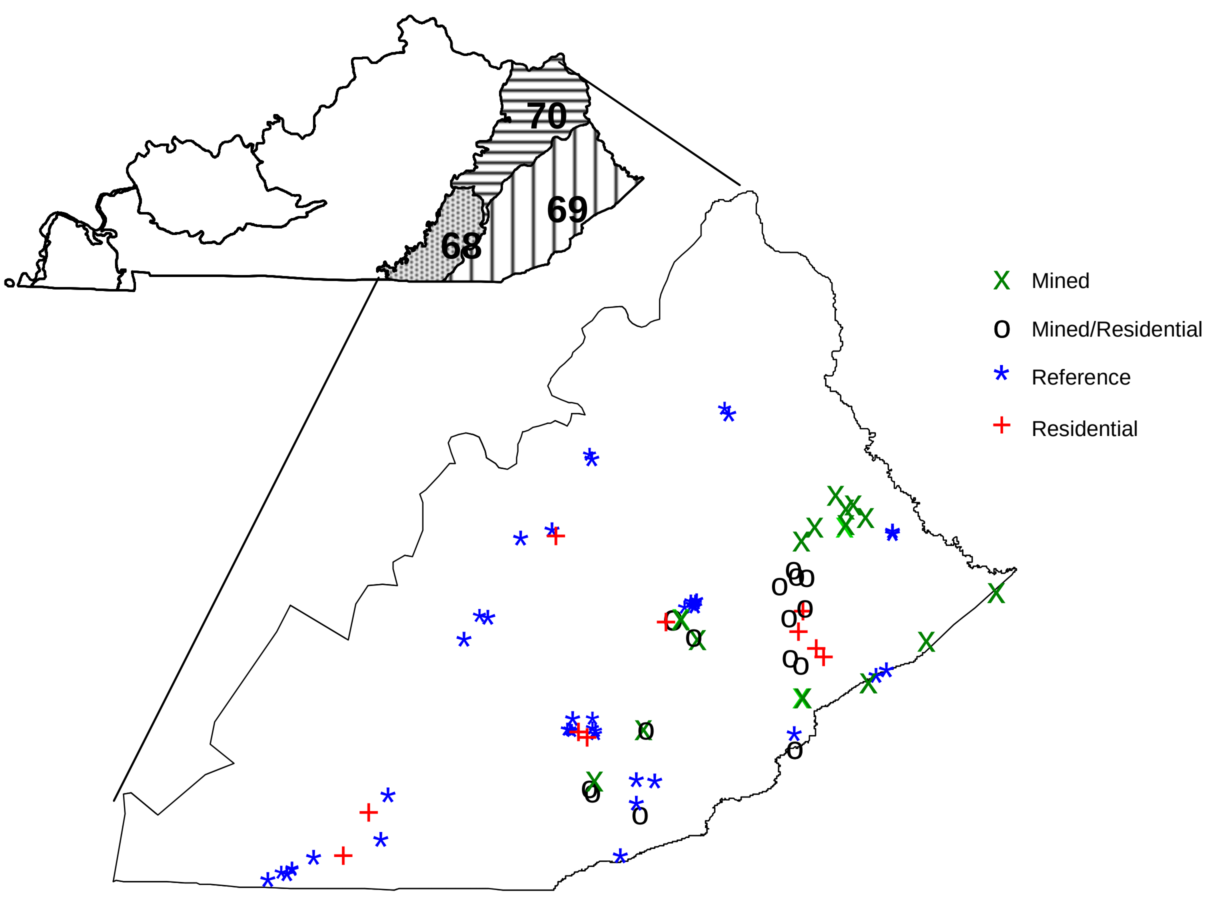

Figure 12. Level III Ecoregions that make up the ECF in Kentucky (a.), and location of sites (b.) coded by land-use category (see below).

Sites were categorized *a priori* into one of four groups (reference, residential, mined/residential, and mined) based on the predominant land use upstream of the sampling reach (Table 1). This categorization generally followed works by Green et al. (2000) and Fulk et al. (2003). To select reference headwater streams, intensive field and desktop reconnaissance was done using a combination of narrative and quantitative physical attributes (KDOW 2002a). Additional agency data were also reviewed (e.g., presence/absence of permitted dischargers, mines, oil and gas development and land cover) to help select candidate reference reaches. Biological data were not used to select reference sites to avoid circularity.

Table 1. Number of sites by category and mean and range (in parentheses) of catchment area (in sq. mi.).

	Total Number of Sites	Catchment Area
Reference	38	1.17 (0.13-3.15)
Residential	9	1.64 (0.3-3.3)
Mined	19	0.93 (0.8-3.7)
Mined/Residential	17	2.26 (0.1-2.81)

For the disturbed site categories, land use was determined using various agency data layers and Geographical Information System software (GIS, Arcview v. 3.1). Topographic maps, aerial photos (March 1995 and February 2002), mining map overlays, permitted dischargers, etc. were reviewed in relation to biological sampling points. Residential sites were included for analysis if >5 homes were situated upstream of the sample reach and had no other permitted activities. Mined/residential sites had some surface mining and more than five residences upstream of the sample point. Mined sites had some surface mining and no residences upstream. The majority of the sites had hollowfills located within their watersheds. Sites that could not be placed into a distinct category defined above were excluded from further analyses. Actual sampling reach selection was generally dependent upon accessibility, position in the watershed, and whether the site was representative of the stream as a whole. Several sites were randomly chosen as part of KDOW probabilistic monitoring program. Some residential and mined/residential sites were considered to have high housing density (>100 houses/mile) within the stream corridor. These same streams' uplands were often up to 80 percent covered in forest. In contrast, many mined sites had mostly forested stream corridors but very little forest in the uplands. In terms of streamside vegetation, residential and mined/residential streams were more likely to have non-native invasive species such as multiflora rose, Japanese honeysuckle, and Japanese knotweed along their banks. Representative sampling sites are shown in Figure 13.

With regard to oil/gas wells and roads, sites were retained for analysis if they had no more than two oil or gas wells upstream of the sampling reach (Kentucky Geological Survey GIS layer). A few reference sites had oil or gas wells in their watershed, but no elevated conductivity (an indicator of brines/chlorides) was detected. Roads of various usage were present in most watersheds and were assumed to contribute similar impacts among disturbed and reference categories.